Observation of the middle atmospheric thermal tides using lidar measurements over Mauna Loa Observatory (19.5°N, 155.6°W).

Thierry Leblanc and I. Stuart McDermid
Jet Propulsion Laboratory, California Institute of Technology, Table Mountain Facility, Wrightwood, CA, USA.
leblanc@tmf.jpl.nasa.gov, Tel: +1 (760) 249 1070, Fax: +1 760 249 5392

1. Introduction

Temperature measurements in the middle atmosphere using Rayleigh lidars have been performed for several decades now. The high accuracy and vertical resolution provided by lidars allow to study the temperature variability at various scales with high confidence levels. One of the numerous applications is the study of the middle atmospheric thermal tides. Although Rayleigh lidar measurements are basically possible only at nighttime, diurnal and semidiurnal components can often be extracted if the results are taken with care and correctly interpreted.

Using results from more than 200 hours of nighttime measurements obtained by lidar in October 1996 and 1997 at Mauna Loa Observatory, Hawaii, a study of the middle atmospheric (25-90 km) thermal tides is presented in this paper. The amplitudes and phases of the diurnal and semidiurnal components were calculated for some altitudes where the fits converged significantly, and compared to that of the Global Scale Wave Model (GSWM).

2. Lidar principle, data sets and data analysis.

Laser radiation transmitted into the atmosphere is Rayleigh backscattered by the air molecules and collected by a telescope. The number of photons received is proportional to the number of photons emitted and to the number of molecules i.e. air density. Except following volcanic eruptions when particular care is required, Mie scattering by aerosols is only important below 25-30 km and can be neglected for the air density derivation above 30 km. Then, the temperature is derived from the air density assuming hydrostatic equilibrium and the ideal gas law [*Hauchecorne and Chanin*, 1980].

10 nights of measurements (typically 11-hours per night from 19:00 to 5:00 Local Solar Time) obtained by the Jet Propulsion Laboratory (JPL) Rayleigh/Raman lidar [McDermid et al., 1992] at Mauna Loa (19.5N) between October 3-16, 1996, and 10 nights obtained between October 2-11, 1997 were used for this study. For both October 1996 and 1997 periods, the raw signal taken every night at a given Local Solar Time (LST) has been summed into a composite raw signal and analyzed to obtain 11 hourly-mean composite temperature profiles (15-95 km). Also, the nightly average temperature profile over the 10 nights in October 1996 and that over the 10 nights in October 1997 has been calculated. The temperature determination by Rayleigh lidar requires an a priori initialization at the top. For the two nightly average profiles the CIRA-86 temperature at 103-105 km was used. Then, for each 1996 hourly-average profile the 1996 nightly average temperature at 93.4 km has been used, and for each 1997 hourly-average profile, the 1997 nightly average temperature at 94 km has been used. Thus it is certain that at these tie-on altitudes the temperature will remain constant throughout the night and the calculated fits for both diurnal and semidiurnal components will result in zero-amplitudes. Then, a few kilometers lower the calculated amplitudes are expected to rapidly increase to their observed values as the temperature is calculated downward and converges into its true value. The total error at the top of a typical temperature profile is about 20 K, rapidly decreasing to few Kelvin 10-15 km below and to less than 1 K 25 km below.

3. Results.

In a first step, for each given LST the temperature difference between the composite profile and the nightly average profile has been calculated. These temperature differences were seen to be LST dependent and were fitted temporally using 2 cosine functions to represent the diurnal and semidiurnal components only. When the nightly average temperature is close to the true 24-hour-average temperature the calculated fits will give correct and significant results. However, this is not true when the nightly average is far from the true 24-hour-average. For this reason, some estimated components were taken from GSWM [*Hagan et al.*, 1995].and introduced to calculate an estimated 24-hour-average to be subtracted from the LST composite profiles. Figure 1 gives the results of the calculated diurnal and semidiurnal amplitudes and phases between 25 and 95 km for the 1996 period, using the phases given by GSWM, and twice the amplitudes given by GSWM for the estimation of the 24-hour average. Unlike GSWM, the calculated amplitudes (in K) and phases (LST) are given with their 1σ standard deviation (horizontal bars). The effect of an 11-hour wide measurement window is clearly seen. The semidiurnal component can be retrieved correctly but the diurnal component can not be well identified at all altitudes.

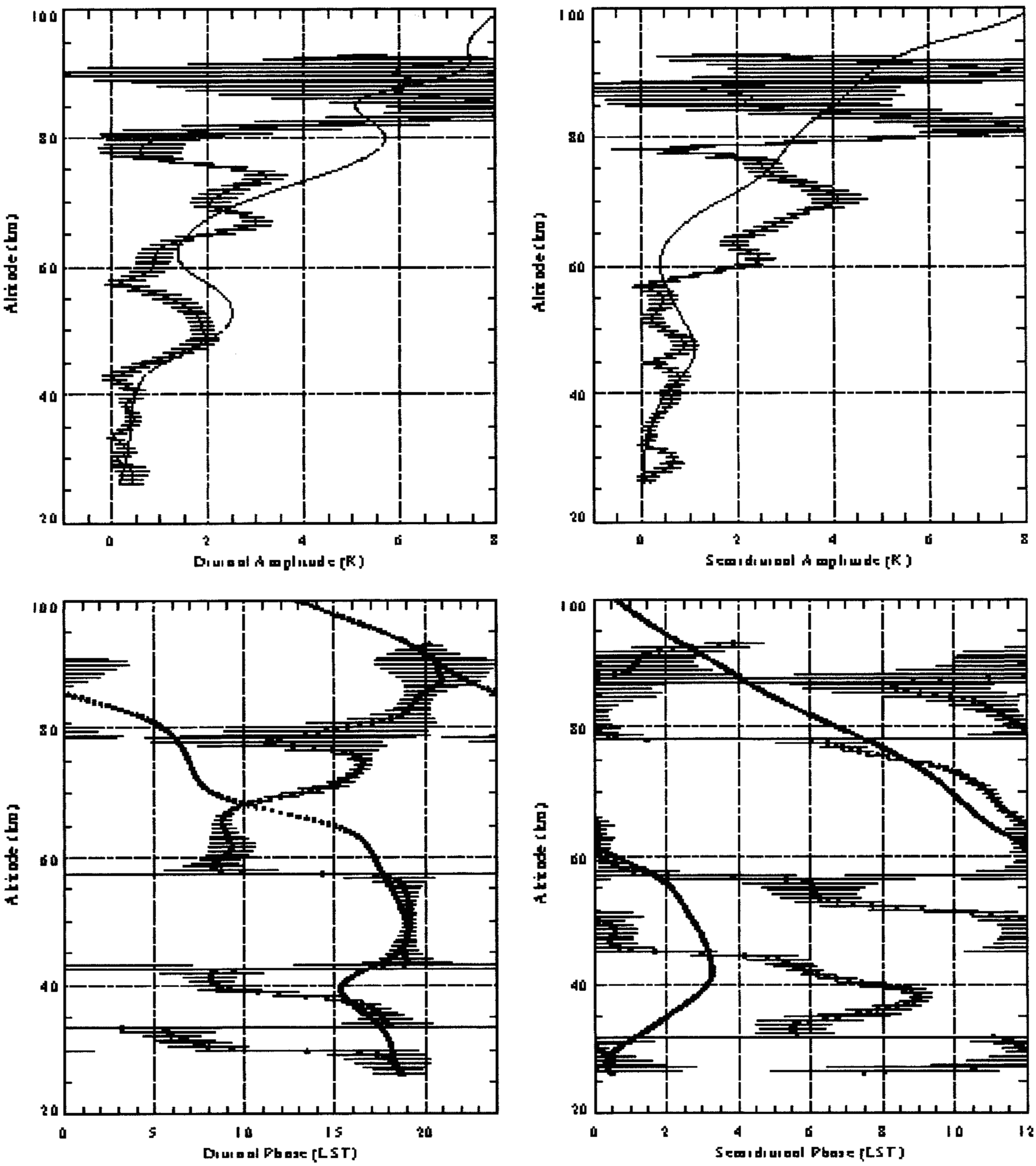

Figure 1: Amplitude (top) and phases (bottom) of the diurnal (left) and semidiurnal (right) components calculated for 10 nights of October 3-16, 1996. The amplitudes and phases are plotted with their 1σ standard deviation (horizontal bars) while twice the GSWM amplitudes and the GSWM phases are represented by single lines and dots.

Basically, the significant results are:

For the semidiurnal component:

a) A small amplitude (< 1K) below 60 km.

b) A maximum amplitude of 4 K at 70 km, with a corresponding phase around 10:00 - 11:00, 2 hours away from the theoretical model GSWM.

c) A minimum of amplitude corresponding to an out-of-phase transition (from 6:00 to 12:00) just below 80 km.

d) An 8 K maximum amplitude at 82 km, with a corresponding phase of 11:00-12:00.

For the diurnal component:

e) A small amplitude (< 1K) below 45 km.

f) A maximum amplitude of 2 K around 47-51 km, with a corresponding phase around 18:00 - 19:00, in good agreement with GSWM.

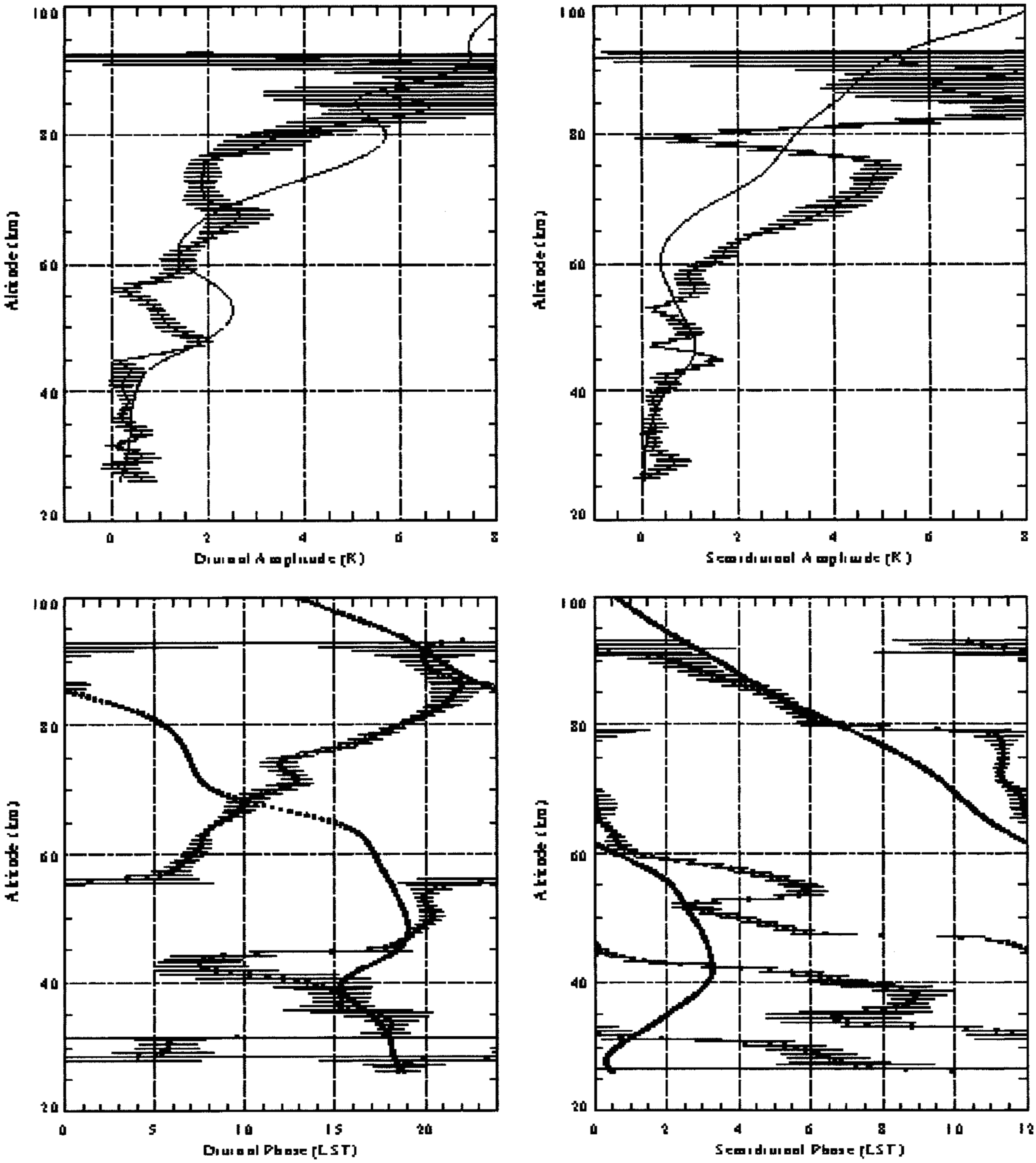

Figure 2. Same as Figure 1 but for the 10 nights of October 2-10, 1997.

g) A minimum amplitude corresponding to an out-of-phase transition (from 19:00 to 7:00) at 57-58 km. This may indicate an actual phase around 12:00 at this altitude.

h) A double maximum of 3 K at 66 and 73 km. The phase corresponding to the upper maximum occurs at 16:00, which is in total disagreement with the 7:00 phase of GSWM.

i) A minimum amplitude at 78 km. Once again, this may indicate an actual phase around 12:00 at this altitude.

First, all results show that the observed amplitudes appear to be twice as large than predicted by GSWM (the modeled amplitudes plotted in Figure 1 are equal to twice the GSWM). Results b) shows that a maximum in the semidiurnal amplitude has not been predicted by the model. Results c) f) g) h) and i) together may suggest the presence of a locally forced diurnal mode at 78 km not predicted by the model, or that the diurnal mode propagating from below 50 km has a near-20-km vertical wavelength, much shorter than predicted and already suggested by [*Dao et al.*, 1995].

Figure 2 is similar to Figure 1 but for the October 1997 period. When compared to the October 1996 period, some remarkably consistent results are found.

For the semidiurnal component:

j) Same as a) with a first secondary maximum in amplitude (1.5 K) around 45 km.
k) Same as b), a maximum amplitude of 5 K around 70-75 km, analog to the result b)
l) A minimum amplitude corresponding to an out-of-phase transition (from 12:00 to 6:00) just below 80 km, but in out-of-phase compared to 1996.

For the diurnal component:

m) Same as e): small amplitude below 45 km.
n) Same as f): Maximum amplitude of 23 K but at 46-47 km instead of 47-51 km, with a corresponding phase around 18:00 - 19:00, in good agreement with GSWM.
o) Same as g): A minimum amplitude corresponding to an out-of-phase transition (from 19:00 to 7:00) at 56 km. Once again, this may indicate an actual phase around 12:00 at this altitude.
p) A phase located at 15:00 around 75 km, once again in total disagreement with GSWM.

6. Summary.

More than 200 hours of nighttime measurements obtained by the Jet Propulsion Laboratory (JPL) Rayleigh/Raman lidar in October 1996 and 1997 located at Mauna Loa Observatory (19.5°N) have been used to extract the diurnal and semidiurnal components in the middle atmospheric temperature (15-95 km) and to compare them to the Global Scale Wave Model (GSWM). Despite a short 11-hour wide measurement window, some significant results have been obtained:
- Both observed diurnal and semidiurnal amplitudes appeared to be twice as large as predicted by GSWM.
- Both diurnal and semidiurnal amplitudes are less than 1 K below 40 km.
- The calculated semidiurnal amplitude has a maximum at 70-75 km, not predicted by GSWM. The corresponding phase is around 11:00 – 12:00, in good agreement with GSWM.
- The calculated diurnal amplitude has a maximum at 45-50 km, with a phase around 19:00, in good agreement with GSWM.
- For both 1996 and 1997 periods, a minimum in the calculated diurnal amplitude associated with an out-of-phase transition from 19:00 to 7:00 is clearly observed at 55-58 km. Since the 11-hour measurement window is centered on 00:00 LST, the diurnal phase at this altitude is likely to be around 12:00 and the true amplitude is likely to be larger than calculated. This minimum, together with the maximum found at 45-50 km and a well defined 16:00 diurnal phase at 75 km may suggest the presence of an upward propagating diurnal mode from below 50 km with a vertical wavelength of approximately 20-km, or the presence of a forced mode trapped around 75 km.
- For both 1996 and 1997 periods, a minimum in the semidiurnal amplitude associated with an out-of-phase transition from 6:00 to 00:00 in 1996, and from 12:00 to 6:00 in 1997 is clearly observed just below 80 km.
- Unlike the diurnal minimum at 55-58 km, the out-of-phase transition at this altitude and the 12 hours difference observed between 1996 and 1997 can not be explained at this date. However, the nightly averaged profiles calculated for 1996 and 1997 appeared to be extremely different especially above 80 km, and may play a major role in modulating and/or ruling the semidiurnal and diurnal components.

More investigations and observations are necessary to confirm these results. In particular, the use of simulated data and the refinement of estimated components for the calculation of a correctly estimated 24-hours average profile should give some important answers for a better understanding of the thermal tides in the middle atmosphere.

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